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Visual spatial attention to stimuli presented on the vertical and horizontal meridian: An ERP study

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Abstract

In the first experiment, 48 subjects carried out a visual spatial attention task. Stimuli were presented at the vertical meridian, either above or below a fixation dot, and the subjects were instructed to attend to one of these stimulus positions and ignore the other position. In three different conditions, the distances between stimulus positions and fixation were 0.5°, 0.9°, and 1.3°. Subjects searched for the presence of prememorized target letters at the attended location: memory load was one or four items in different conditions. The P1/N1 enhancement typically found on the horizontal dimension was not observed on the vertical dimension. Instead, a positive shift of the attended compared with the unattended stimuli was found, which was most prominent at anterior electrodes. This positivity showed effects of the distance manipulation. The N2b-P3a effect of attention and the effect of memory load (search negativity) normally present in this kind of selective search task were also found. Reaction times were faster when attention was directed above fixation than when it was directed below fixation. The event-related potential data suggested that this difference could be attributed to a more efficient neglecting of irrelevant stimuli presented below fixation. In Experiment 2, we examined whether the absence of the P1/N1 enhancement as the result of spatial attention in Experiment 1 could be attributed to (a) the presentation of stimuli along the vertical meridian instead of along the horizontal meridian, (b) the use of midline electrodes instead of lateralized electrodes, and (c) the relatively small spatial separation between the relevant and irrelevant stimuli. Twelve subjects searched for the presence of a single target letter at an attended position in three different conditions. In two of the conditions the letters were presented to the left or right of fixation. The distance between fixation and the stimulus positions was 1.3° in one of these conditions and 3° in the other condition. In the third condition, the stimuli were presented at 3° above or below fixation. In all three conditions effects similar to those in Experiment 1 were observed. In addition, in all three conditions an enhancement of the P1 and N1 components was found at two lateral occipitotemporal electrodes.

Descriptors: Event-related potentials, Selective attention, Vertical meridian, Horizontal meridian

The study of selective attention focuses on the effects of stimulus relevance on information processing. In the prototypical experiment, stimulus relevance is manipulated by instruction or task structure with relevant (to be attended) and irrelevant (to be ignored) stimuli being discriminated on the basis of simple physical characteristics. In most research on selectivity in the visual modality, relevant and irrelevant stimuli are presented at different locations in the visual field (i.e., spatial attention). Spatial attention also plays a special role in recent influential theories of visual selective attention. For example, feature-integration theory (Treisman & Gelade, 1980) equates selective attention with a spatial scanning mechanism that serves to form conjunctions of preattentively registrated elementary visual features (e.g., color, form). It has been suggested that the special status of spatial location as a selection cue (i.e., the visual attribute on the basis of which relevant and irrelevant information can be discriminated) follows from principles of cerebral organization. Because different visual features appear to be represented in separate spatiotopically organized brain maps (Cowey, 1985), localization (spatial attention) is required to relate different features to one another (Nissen, 1985; Treisman, 1988).

Much behavioral research has been aimed at comparing the efficiency of processing (indexed by reaction time and accuracy) at cued (attended) and uncued (unattended) locations. A popular view has emerged from this research in which attention is described as a mental spotlight (e.g., Posner, Snyder, & Davidson, 1980) or zoom lens (Eriksen & St. James, 1986; Eriksen &

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Yeh, 1985) that enhances the efficiency of processing within its beam and moves independent of eye fixation. This spotlight apparently cannot be divided over two nonadjacent areas (Eriksen & Yeh, 1985; Posner et al., 1980), and several studies have sought to determine the speed with which the spotlight is moved from one location to another (LaBerge & Brown, 1986; Remington & Pierce, 1984; Shulman, Remington, & McClean, 1979; Tsal, 1983). The distribution of attentional resources within the spotlight has also been investigated, some authors arguing that resources are evenly distributed over the entire span of the beam or zoom lens (Eriksen & St. James, 1986; Eriksen & Yeh, 1985), others arguing for an uneven distribution (gradients of attention: Shulman, Sheehy, & Wilson, 1986; Shulman, Wilson, & Sheehy, 1985). The size of the spotlight appears to be task dependent (Downing, 1988; Eriksen & St. James, 1986; Eriksen & Yeh, 1985; LaBerge, 1983). Employing the signal-detection paradigm, some authors have reported that spatial attention enhances perceptual sensitivity (Bashinski & Bacharach, 1980; Downing, 1988; Hawkins et al., 1990; Heinze, Mangun, & Hillyard, 1990), whereas Müller and Findlay (1987) found that spatial attention influenced both sensitivity and response bias in a symbol detection task, but only response bias in a luminance increment detection task.

Unfortunately, to interpret behavioral results in terms of one of the characteristics of the attentional spotlight (e.g., speed of movement), strong assumptions must be made regarding the other characteristics (e.g., that there is a small spotlight with evenly distributed resources) (Eriksen & Murphy, 1987). Also, it is hard to deduce from behavioral research either the stage of processing at which spatial attention has its effects or the brain mechanisms involved in the selection process.

Event-related potential (ERP) research offers an alternative methodology that has provided important insights into the temporal and organizational aspects of selection mechanisms as a function of different selection cues or combinations of selection cues. This research has confirmed that spatial location has a special status as a visual selection cue. ERP effects of spatial attention start earlier (at about 100 ms poststimulus) than effects of nonspatial attention (dependent on type and discriminability of selection cue, but earliest onset at about 150 ms). Although nonspatial selection results generally in slow, occipitally maximal selection negativities (Harter & Aine, 1984), spatial attention results in amplitude enhancements of a series of components over the posterior scalp, but most consistently so for the P1 (peaking between 100 and 140 ms) and N1 (160–190 ms) components. Moreover, selection of stimuli on the basis of color is dependent on a prior selection with respect to spatial location (Hillyard & Münte, 1984; Wijers, Lamain, Slopsema, Mulder, & Mulder, 1989a), whereas selection for orientation and spatial frequency proceed independently (Previc & Harter, 1982). There is also evidence from ERP research that spatial attention is not narrowly constricted to a small visual area but that there is a gradient of attention. It has been argued that some attentional resources can be allocated to a location at a distance of 5° from the relevant location (Mangun & Hillyard, 1987, 1988, 1990).

Theories have been formulated to relate such ERP findings to underlying neurophysiological mechanisms. Harter and Aine (1984) proposed that spatial attention is mediated by efferent modulation of the neural channels of the fast, tectopulvinar visual projection system (which is thought to primarily process location and movement), whereas nonspatial attention modulates the neural channels of the slower, geniculostriate cortex (thought to process form, pattern, and color). Hillyard and coworkers have interpreted the enhancement of the exogenous P1 and N1 components as evidence for a process of selective sensory gating or gain control in the visual pathways as the result of spatial attention. Hillyard, Münte, and Neville (1985) and Hillyard and Mangun (1986) suggested that these enhancements may reflect a subcortical gating mechanism, filtering information prior to its arrival at the primary occipital cortex. In a more recent formulation Mangun, Hillyard, and Luck (1993) located spatial attention effects at the level of the secondary visual areas. Their ideas are based on recent neuroanatomical evidence suggesting that two processing pathways may be distinguished, both of which originate in the striate cortex; the dorsal stream projects to the parietal cortex and appears to be crucial for spatial perception and visuomotor performance, and the ventral stream projects to the temporal cortex and is crucial for object recognition (Desimone & Ungerleider, 1989). Thus, in contrast to the neural-specificity theory of Harter and Aine (1984) it appears that the processing of location and movement also involves geniculostriate projections. On the basis of the scalp topographies of the P1 and N1 components for attended and unattended stimuli, Mangun et al. (1993) suggested that the P1 component is generated in the lateral prestriate cortex and that the effect of spatial attention on this component reflects a modulation of attention on the ventral stream of processing (i.e., spatial attention enhances feature analysis and object recognition processes for stimuli at attended locations and/or inhibits these processes for unattended stimuli). The N1, however, was thought to reflect the spatially selective functions of the dorsal projection stream and was believed to reflect switching of attention to relevant locations.

The characteristics of spatial attention could depend on where in the visual field attention is directed and/or where the relevant and irrelevant locations are positioned relative to each other in the visual field. For example, reaction time analyses indicate that the attentional spotlight encompasses a larger visual area the further it is removed from the point of fixation (Estes, 1982; Humphreys, 1981; Shulman et al., 1985, 1986). Furthermore, perceptual sensitivity (d') falls off more steeply over distance when irrelevant stimuli are presented near to the attended location than when they are presented farther apart (Downing, 1988).

One specific question that remains relates to whether spatial attention is different for situations in which selection takes place between visual half-fields, within a visual half-field, or between the upper and lower visual half-fields. Although in most ERP research relevant and irrelevant stimuli are presented to the left and right visual half-fields, the upper versus lower half-field mode of selection has been seldom explored. In the present study, stimuli were presented on the vertical meridian, at a location either above or below fixation, and subjects were instructed to attend to one of these locations. Moreover, the spatial distance between the two locations and fixation differed among three different distances. It was hoped that this manipulation would increase our knowledge about the size of the minimal visual area to which the attentional spotlight can be constricted.

In addition, the experiment aimed to extend findings obtained with a selective search task. In such studies, the stimuli are typically letters and the subjects are required to decide whether the letters on the attended, relevant location belong to a set of prememorized letters (memory set). The subjects are required to respond only to relevant memory-set letters (targets).

In previous research with this task it was observed that relevant stimuli showed a late (about 200–400 ms) centrally maximal negativity (N2b) as compared with irrelevant stimuli, independent of the selection cue (diagonal: Okita, Wijers, Mulder, & Mulder, 1985; color: Wijers, Mulder, Okita, Mulder, & Scheffers, 1989c; letter size and conjunctions of letter size: Wijers, Mulder, Okita, & Mulder, 1989b). This N2b followed earlier effects of attention in the case of spatial and color selections. Increasing the size of the memory set resulted in a prolonged centrally maximal negativity (onset at about 300 ms, duration several hundred milliseconds). The presentation of relevant target letters resulted in a parietally maximal late positivity (P3b).

The present experiment also served as a control condition in research on the role of spatial attention in reading (Gunter, Jackson, Kutas, Mulder, & Buijink, in press); spatial attention along the vertical dimension serves to ignore text above and below the line currently being read.

Experiment 1

Method

Subjects

Forty-eight subjects (24 women, 24 men) served as paid volunteers. Their ages were between 18 and 23 years, and all had normal or corrected-to-normal vision. Two of the men reported themselves to be left handed.

Stimuli and Apparatus

Subjects were seated in a dimly lit, sound attenuated, electrically shielded room, facing a color video monitor at a distance of 100 cm. They received blocks of 240 stimulus frames. A small central dot remained visible throughout the entire block and indicated the position to be fixated. Depending on memory load condition, each block was preceded by a new memory set of 1 (M1) or 4 (M4) letters. This memory set was presented for 10 s, either above or below fixation, indicating the location to be attended during the subsequent stimulus series. Thus, the memory set and relevant location remained constant for one block of trials but changed between blocks. The stimuli consisted of single letters presented on a vertical axis, either at a location above or below fixation. The stimulus letters were presented for 55 ms, and the interstimulus interval varied randomly, in steps of 100 ms, between 955 and 1,155 ms. The white letters, which had a height of 0.6°, were presented on a dark background. All subjects received a condition in which the stimulus letters, both above and below fixation, were presented at a distance of 0.5° from the fixation dot (distance to nearest side of the letter); half of the subjects received a second condition in which this distance was 0.9°, whereas the other half received a second distance of 1.3°.

For each block of 240 trials, 120 trials were letters presented at the relevant (i.e., to be attended) location, and 120 trials were irrelevant. Within both the relevant and irrelevant stimulus classes, 40 trials were target trials, consisting of a letter from the memory set. The task of the subject was to detect target letters at the relevant location and to respond only to these stimuli.

The memory set letters were randomly chosen from the set B, C, D, F, G, H, J, K, L, M, N, P, R, S, T, V, W, X, and Z. Relevant and irrelevant, and target and nontarget trials were presented randomly with the exception that relevant targets could not occur on two subsequent trials. The stimulus letter was chosen randomly from the memory set for target trials and randomly from the remaining set of letters for nontarget trials. The timing of the stimuli, the exposure duration, and the measurement of reaction time (RT) and errors were under control of an IBM-compatible AT computer.

Procedure

The subject's task was to detect target letters from the memory set at the relevant location and to respond to these relevant targets by lifting the right index finger. The subjects were instructed to respond as quickly and accurately as possible. The experiment consisted of eight conditions defined by combinations of the following variables: memory load 1 (M1) versus memory load 4 (M4) conditions; attend the location above fixation versus attend the location below fixation; a small distance and a larger distance between fixation and stimulus locations. The order of administration of the memory load conditions and the attend upper/lower position conditions was counterbalanced both within and across subjects. For each condition, two different stimulus series were prepared, using different memory set letters. These series were balanced across subjects (between-subjects variable *task version*). The subjects first received four blocks (M1/M4, attend upper/lower) with a small stimulus-fixation distance and then four blocks with a larger distance. For all of the subjects, the distance in the first four blocks was 0.5°; the next four task blocks were either 0.9° or 1.3°, depending on the experimental condition of the group.

Subjects were given two practice blocks (one block M1 and one block M4). If they missed more than 10% of the relevant targets, an additional M4 block was given. A short rest period of 1–3 min was provided between blocks.

Recording

The electroencephalogram (EEG) was recorded with Ag-AgCl electrodes from Fz, Cz, Pz, Oz, Tl (75% of the Cz–T3 distance), and Tr (75% of the Cz–T4 distance), referred to the right mastoid. Electrode resistance was kept below 2 kohm. The electrooculogram was recorded bipolarly between electrodes situated on the outer right canthus and above the eye brow of the right eye. These signals were amplified, bandpass filtered between 0.01 and 35 Hz, and digitized on-line at a rate of 100 Hz.

Data Analysis

Average ERPs were computed separately for each electrode location for the 32 classes defined by stimulus location (above vs. below fixation); attention (attention directed at the location of stimulus presentation vs. directed at the opposite location); letter category (memory set letter vs. nontarget letter); memory load condition (M1 and M4); and small versus larger stimulus–fixation distance. The averaging epoch began 280 ms prior to stimulus onset and lasted until 1,000 ms poststimulus. Epochs containing ocular (criterion 50 μV) or amplifier-saturating artifacts or incorrect responses (misses, false alarms) were excluded. The averaged ERPs were aligned to a 100-ms prestimulus baseline.

Each ERP was divided into 33 periods of 30 ms, from 10 to 1,000 ms poststimulus (e.g., Interval 10 is a mean of 10, 20, and 30 ms; Interval 40 is a mean from 40 to 60 ms, etc.). The mean amplitudes of the ERPs in these intervals (i.e., the mean of three sample points) were submitted as dependent variables to SPSSPC+ multivariate analyses of variance (MANOVAs). The multivariate approach to repeated measurements was used, thereby avoiding problems concerning sphericity (e.g., O'Brien

& Kaiser, 1985; Vasey & Thayer, 1987). If significant effects in a particular range are reported, all mean amplitude variables in this range showed significant effects ($p < .05$). Effects will only be presented when two or more successive amplitude variables show significant effects. All analyses were carried out for each electrode position separately. In the main design, the following within-subjects variables were tested: stimulus location (below/above fixation), attention (attended/unattended), stimulus category (target/nontarget), memory load (M1/M4), and distance (small/large). Distance group (0.9° group vs. 1.3° group) was tested as a between-subjects variable.

Peak latencies of P2 and P3b were evaluated using an interactive peak detection program. P2 was obtained at all electrode sites in a 100–200-ms poststimulus search window. P3b was measured at the parietal electrode in the 440–760-ms latency range.

Finger lifting responses to relevant targets, between 290 ms poststimulus and the end of the interstimulus interval (between 955 and 1,155 ms) were scored as hits. From these RT data, mean RT, standard deviation of RT (*SD*), and number of correct answers were computed. These performance measures and the P2 and P3b latency data were analyzed as follows. To test for group differences per se, we first compared the 0.9° group with the 1.3° group for the 0.5° distance condition only. The data were then analyzed separately for both distance groups, with distance, memory load, and attend above/below as within-subjects variables and task version as a between-subjects variable. We also compared the 0.9° distance condition of the 0.9° group with the 1.3 distance condition of the 1.3° group with attend above/below and memory load as within-subjects variables and distance and task version as between-subjects variables.

Results

Performance Data

None of the analyses showed a main effect of or an interaction with task version. The distance group comparison (the 0.9° group vs. the 1.3° group) for the 0.5° distance condition showed that there were no differences between the groups.

The analyses of the data of the 0.9° group (0.5° and 0.9° distance conditions) showed a main effect of memory load, indicating that RT in the low memory load condition (M1) was approximately 90 ms faster than in the high memory load condition (M4) ($F[1,22] = 465$, $p < .0001$) (Table 1). A main effect of attend above/below indicated that RT in the attend above condition was faster than in the attend below condition (11 ms, $F[1,22] = 21.4$, $p < .0001$). A marginally significant interaction of memory load with distance ($F[1,22] = 3.3$, $p = .083$) showed that in the M1 condition there was no difference between the 0.5° and 0.9° distance conditions, whereas in the M4 condition RT in the 0.9° condition was 12 ms faster than in the 0.5° condition.

Similar effects were found in the analyses of the data of the 1.3° group (0.5° and 1.3° distance conditions) (Table 1). For this group, there was also a main effect of memory load ($F[1,22] = 255$, $p < .0001$); RT was 90 ms faster in the M1 condition than in the M4 condition. Furthermore, there was a significant main effect of attend above/below ($F[1,22] = 4.88$, $p < .038$) and an interaction of Memory Load × Fixation-Stimulus Distance ($F[1,22] = 4.31$, $p = .05$). These effects reflected that RT was 10 ms faster in the attend above condition than in the attend below condition and that for the M4 condition RT was 11 ms faster in the 1.3° distance condition than in the 0.5° condition, whereas there was no such difference for the M1 condition.

Table 1. *RT Data (ms) of the Relevant Target Stimuli in Experiment 1 for Memory Load and Attend Position*

	Memory load		Attend position	
Distance condition	M1	M4	Above	Below
0.5°	421	518	473	466
0.9°	420	506	469	458
1.3°	423	504	469	458

No significant effects were found in the comparison of the 0.9° condition of the 0.9° group with the 1.3° condition of the 1.3° group.

The analyses carried out on percentage correct scores showed a memory load main effect, indicating that performance was about 2% more accurate in the M1 condition than in the M4 condition. This effect was found both for the 0.9° group ($F[1,22] = 12$, $p < .002$) and for the 1.3° group ($F[1,22] = 6.4$, $p = .019$).

In summary, the behavioral data indicate that processing in the low memory load condition was faster and more accurate than in the high memory load condition. Targets presented at an attended location above fixation are responded to faster than targets presented at an attended location below fixation. Finally, increasing the distance between the attended and the unattended locations enhances the speed of processing in the high memory load condition.

ERPs

P3b. Effects of attention, presentation above/below fixation, and memory load were comparable for target and nontarget stimuli. The ERPs for unattended nontargets and for unattended targets were very similar (see Figure 1). The main difference between attended targets and attended nontargets consisted of a pronounced late positivity with a maximum at the Pz electrode; this component is identified as P3b (see Brookhuis, 1989) (Table 2).

P3b amplitude and latency were submitted to the same statistical analyses as the performance measures. These analyses indicated that there were no effects of task version nor any interactions with this variable.

For both distance groups there was a main effect of memory load on P3b latency; P3b latency was shorter in the low memory load condition (M1) than in the high memory load condition (M4) (0.9° group: $F[1,22] = 60.8$, $p < .0001$, 1.3° group:

Table 2. *P3b Data of the Relevant Target Stimuli in Experiment 1 for the Attend Position and Memory Load*

	P3b latency (ms)				P3b amplitude (μV)	
Distance condition	Above	Below	M1	M4	M1	M4
0.5°	496	489	454	531	22.4	17
0.9°	472	485	444	512	22.5	18.6
1.3°	485	502	454	534	22.9	17.1

$F[1,22] = 98.9$, $p < .0001$). For P3b amplitude, both distance groups showed a highly significant memory load effect (0.9° group: $F[1,22] = 60.8$, $p < .0001$, 1.3° group: $F[1,22] = 57.8$, $p < .0001$). P3b amplitude was larger in the M1 condition than in the M4 condition (a difference of approximately 5 μV for both groups). In summary, both P3b latency and P3b amplitude were affected by memory load.

When the effect of attending below versus above fixation was tested separately for the three different fixation-stimulus distances, the effect was significant only for the 1.3° distance ($F[1,22] = 10.8$, $p < .003$); P3b latency was 18 ms faster for relevant stimuli presented above fixation than for relevant stimuli presented below fixation.

Effects of stimulus presentation above/below fixation. Presenting a stimulus above or below the fixation point (i.e., the actual presentation position) resulted in different ERP patterns, particularly at the occipital electrode. In Figure 1, this effect is shown for all four stimulus classes. ERPs for stimuli presented above fixation are more positive than ERPs for stimuli presented below fixation in an early latency range (significant effects were obtained in the range 100–270 ms for the interval data). In a later latency range, the ERPs were more negative when stimuli were presented above fixation (main effects above/below in the range 310–570 ms for the interval data), but this effect was only present for unattended stimuli. The only variable showing an interaction with stimulus position above/below fixation was attention (i.e., interval data, see Table 3).

Effects of selective attention. Effects of attention were assessed by comparing the ERPs for attended and unattended nontargets, which were uncontaminated by overt responding. Figure 2 shows a superimposition of ERPs for attended and unattended stimuli and for stimuli presented above and below fixation and a superimposition of the attended-unattended difference waves for stimuli presented above and below fixation.

Both attended and unattended nontargets elicited a P1, which was most clearly visible at the Oz electrode for stimuli presented above fixation, an N1 most clearly visible at Oz for stimuli presented below fixation, and a P2 most pronounced at anterior electrodes (Cz and Fz).

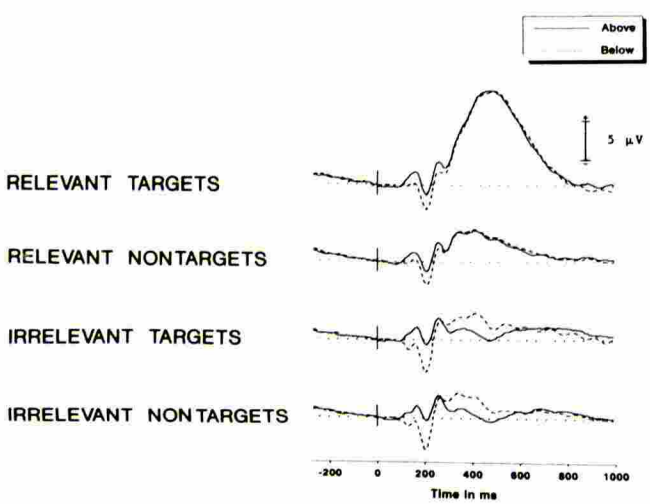


Figure 1. All four categories divided into present above (solid line) and present below (dashed line) fixation (Oz) collapsed across both memory load conditions.

The effect of attention consisted of three phases, which were different in localization and were differently affected by stimulus position (Figure 2). In the first phase (about 100–240 ms), ERPs for attended stimuli were more positive than ERPs for unattended stimuli (except for the ERPs for stimuli presented above fixation, measured at Oz). This effect was widely distributed over the scalp; the difference potentials showed prominent positivities at Fz, Cz, and Pz and somewhat smaller amplitudes at Tl and Tr. The onset latencies of the effects of attention, as estimated by significant main effects of attention on the mean amplitude measures, were 130 ms for Fz, 160 ms for Cz and Pz, and 130 ms for Tl and Tr. For the Oz electrode, the effect of attention depended on stimulus position. For stimuli presented above fixation, the ERPs for attended stimuli were more negative than those for unattended stimuli, whereas for stimuli presented below fixation the ERPs for attended stimuli were more positive. This pattern of results was supported by significant Attention × Position (above/below) interactions in the 100–240-ms range. Tested separately, the effect of attention was significant in the 100–210-ms range for stimuli presented below fixation and in the range 190–240 ms for stimuli presented above fixation.

The P2 component peaks earlier for attended than for unattended stimuli at the anterior electrodes (Fz, Cz, Pz) (Figure 2). One might wonder whether attention actually influenced P2 peak latency or whether the P2 peak only apparently seemed to be shifted because of the overlap with an endogenous attentional early positivity and later negativity. In the former case one would expect the P2 to have similar scalp distributions for the attended and unattended stimuli. However, a highly significant interaction of Attention × Electrode ($F[3,42] = 14.4$, $p < .0001$) for the P2 amplitude measure indicated that the scalp distribution of the P2 was different for attended and unattended stimuli. An additional analysis using the McCarthy and Wood (1985) scaling procedure confirmed the observation of this significant interaction ($F[3,45] = 13.8$, $p < .0001$).

The second phase of the effect of attention consisted of a negativity of the ERPs for attended stimuli as compared with those for unattended stimuli (in the latency range of about 250–400 ms). This effect was visible at all electrode sites but was largest at Cz and Fz. This negativity was followed by a third phase, in which the ERPs for attended stimuli were more positive than those for unattended stimuli. Again, this effect was observed at all electrodes, but the positivity was largest at Pz and Cz.

The negative phase of this biphasic difference wave was somewhat larger for stimuli presented below fixation than for stimuli presented above fixation (see Figure 2, right panel). This difference can be attributed mainly to the unattended stimuli, which evoked somewhat more negativity in the N2b latency range when they were presented above fixation (and thus a smaller difference wave) (Figure 2, left and middle panels).

In summary, selecting a stimulus on the basis of its presentation above or below fixation resulted in an early positivity in the ERPs for attended stimuli as compared with those for irrelevant stimuli at all electrode sites except for Oz, where the effect of attention was also a positivity for stimuli presented below fixation but a (nonsignificant) negativity for stimuli above fixation. The earliest attention-related effects were observed at Oz for stimuli presented below fixation (onset latency at 100 ms post-

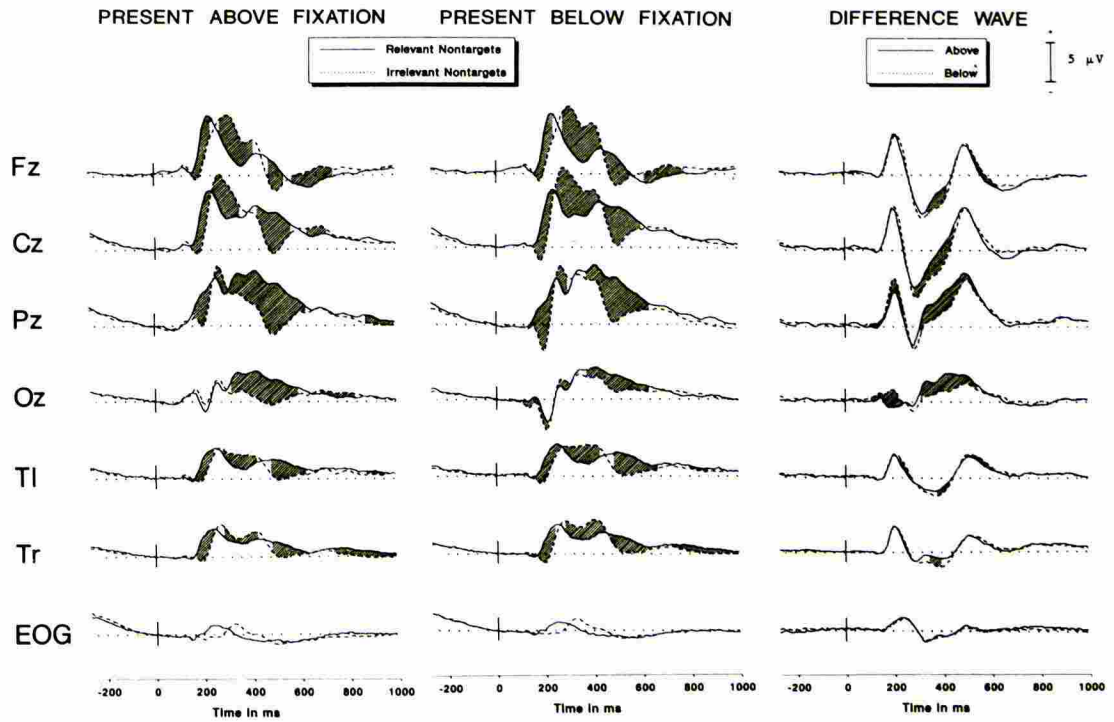


Figure 2. The left and middle panels show relevant nontarget (solid line) and irrelevant nontarget (dashed line) stimuli for presentation above (left panel) and below (middle panel) fixation. The right panel shows difference waves for attended minus unattended nontarget stimuli for present above (solid line) and present below (dashed line) fixation. The shaded areas show a significant ($p < .05$, typically $p < .001$) difference between the depicted traces. All traces represent data collapsed across both memory load conditions.

stimulus). This early attention-related ERP effect was followed by a later negative-positive complex (onset at about 240 ms). The negative phase of this N2b-P3a complex was somewhat smaller for stimuli presented above fixation, mainly because unattended stimuli presented at this position evoked more negativity than did unattended stimuli presented below fixation.

Effects of memory load. The effect of memory load consisted of a late prolonged negative shift of the ERPs in the M4 condition as compared with the ERPs in the M1 condition. This negative shift was mainly confined to the ERPs for attended stimuli, as indicated by significant Memory Load × Attention interactions (see Table 3 and shaded latency ranges in Figure 3). However, tested separately for unattended stimuli, the memory load effect reached significance at Fz (520–600 ms), Cz (160–360 ms), Pz (130–690 ms), Oz (130–270 ms and 460–660 ms), and Tr (250–360 ms). The memory load effect was largest at Cz and Fz but was also quite pronounced at Tl and Tr. Figure 3 shows the attended-unattended difference wave superimposed for the M1 and M4 conditions. Memory load did not have an effect on the early phase of the difference wave; differences between memory conditions started at the peak of the N2b (at about 280 ms at Cz).

Interactions of memory load with distance or with stimulus position above/below fixation did not reach statistical significance.

In summary, there is a clear effect of memory load modulating the effects of attention, starting at approximately 280 ms

Table 3. *Significant[a] Epochs in Experiment 1 for the Interaction of Relevance With Presentation Above/Below Fixation, Memory Load, and Fixation Distance*

Electrode	Above/below	Memory load	Distance
Fz	10–40, 340–400, 520–610	360–490, 640–970	190–220
Cz	280–430	280–460	190–220
Pz	100–220, 310–520	460–670, 880–970	160–250, 400–450
Oz	100–220, 310–520	220–250, 460–700	160–480
Tr	220–250, 370–400, 490–580	310–520, 790–970	190–220
Tl	220–250, 340–370	340–550, 700–820	190–220

[a] $p < .05$, typically $p < .001$.

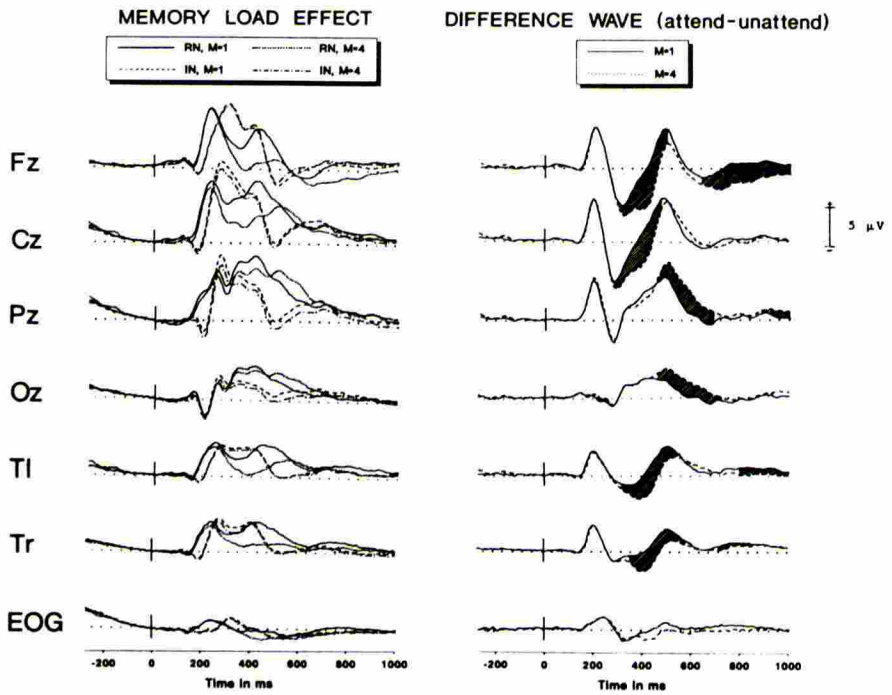


Figure 3. The left panel shows relevant nontarget (RN) and irrelevant nontarget (IN) stimuli separately for both memory loads (M1, M4). The right panel shows difference waves for attended-unattended nontargets for memory load 1 (solid line) and memory load 4 (dashed line). The shaded areas show a significant ($p < .05$) difference between the depicted traces.

after stimulus presentation (Cz electrode) and lasting for approximately 200 ms.

Effects of distance. Main effects of distance were present at Fz (160–240 ms), Cz (160–240 ms), Tl (190–270 ms), and Tr (190–270 ms). Distance interacted with attention at all electrodes (see Table 3). Figure 4 shows that this interaction reflects the slight increase in the early positivity in the ERPs for attended stimuli relative for unattended stimuli with fixation-stimulus distance.

In summary, fixation-stimulus distance modulated the attentional effects after approximately 160 ms (Pz, Cz), lasting approximately 100 ms. This effect is small and maximal for the 1.3° condition.

Discussion

The main purpose of Experiment 1 was to investigate ERP signs of spatial selection between the upper and lower visual half-fields. An early effect revealed a positivity of the ERPs for attended stimuli as compared with the ERPs for the same stimuli when unattended. This effect was most pronounced at the anterior electrodes, where the effect started to become significant at about 130 ms. At Oz, a similar (although smaller) positivity became significant at 100 ms for stimuli presented below fixation but was absent for stimuli above fixation. The P1/N1 enhancement that is usually observed in spatial attention tasks with stimuli in the left and right visual half-fields was not obtained in the present experiment. Stimuli above fixation showed the clearest occipital P1 component but no effect of attention, whereas the stimuli below fixation showed the most prominent occipital N1 component but a smaller N1 for attended stimuli.

The early effect of attention was followed by a biphasic centrofrontal negativity and parietocentral positivity. A similar negative-positive attention-related complex has repeatedly been observed in previous research using comparable selective search tasks but different selection cues, namely color (Wijers et al., 1989c), diagonal (Okita et al., 1985), and letter size (Wijers et al., 1989b). This complex has been interpreted as a N2b-P3a complex, reflecting a feature-nonspecific attentional mechanism, namely covert orienting of attention to stimuli after they have been classified as being relevant.

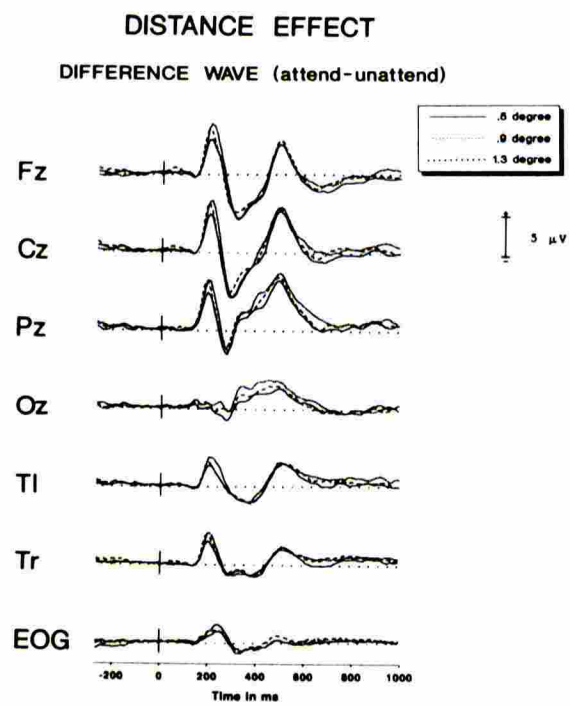


Figure 4. Difference waves of attended minus unattended nontargets for the 0.5° (solid line), the 0.9° (dashed line), and the 1.3° (dotted line) conditions.

As is also usual in search tasks, the relevant nontargets showed effects of memory load consisting of the ERPs in the high memory load being shifted negatively as compared with the ERPs in the low memory load. This search negativity was most clearly visible at the frontal and central electrodes. The effect of memory load is usually confined to the ERPs for attended stimuli, suggesting that the search process can voluntarily be controlled by selective attention (Okita et al., 1985; Wijers et al., 1989c). In the present study, a small though significant effect of memory load was also found in the ERPs for unattended stimuli; a similar finding was obtained by Wijers et al. (1989b) with letter size as a selection cue. This result could indicate that the vertical dimension is not an efficient selection cue (maybe because of the relatively small spatial distance between the relevant and irrelevant positions; see Experiment 2), so that the search process could not be selectively restricted to the relevant channel.[1]

Presenting a stimulus in the upper versus lower visual half-field gave rise to marked ERP differences, which were most prominent at Oz. ERPs for stimuli presented above fixation showed a long duration positivity (in the 100–270-ms range) as compared with the ERPs elicited by stimuli below fixation. Differences in scalp distribution and inversions of polarity for early visual evoked potential components as a function of lower versus upper visual field stimulation have been reported frequently (e.g., Butler et al., 1987; Jeffreys & Axford, 1972a; Ossenblok & Spekreijse, 1991). Such effects have been attributed to the representation of the peripheral visual fields in striate and extrastriate cortex, with the upper and lower half-fields represented on the lower and upper leaves of the calcarine fissure, respectively. However, it is troublesome to relate those findings directly to the present results. In this previous research, the evoked potential component structure was rather different from what was observed here. This difference can probably be attributed to differences in stimulation. Previous research employed checkerboard stimulation of the visual half-fields, quadrants, or octants. Even with similar checkerboard stimulation some inconsistent findings have been obtained. For instance, Jeffreys and Axford (1972a) observed two early components (CI at about 70 ms and CII at about 100 ms), which were positive-negative for lower field stimulation and negative-positive for upper field stimulation. An inversion of the polarity of the CI component for upper versus lower visual field has also been reported by Butler et al. (1987). Ossenblok and Spekreijse (1991), however, failed to observe such an inversion of polarity for any of the early responses. Also regarding the cortical origins of the early components of the visually evoked responses, different hypotheses have been formulated. According to Jeffreys and Axford (1972a) and Butler et al. (1987), the CI component has a striate origin. Others have suggested that the CI and CII have extrastriate and striate origins, respectively (Maier, Dagnelie, Spekreijse, & Van Dijk, 1987; Van Dijk & Spekreijse, 1989). Another complicating factor is that the responses originating in different visual areas may show substantial overlap, so that single ERP peaks may reflect the simultaneous activities of different cortical areas (Ossenblok & Spekreijse, 1991). Thus, a direct comparison of our results with effects obtained with checkerboard stimulation seems rather speculative. Nevertheless, the earliest ERP responses in the present experiment were negative with presentation below fixation and positive with presentation above fixation; this result resembles what has been observed for the CII component. In addition, stimulation in the central visual region (as we did here) contributes heavily to the CII component (Jeffreys & Axford, 1972b).

Performance differences (RT) depended on orientation of attention. Attending above fixation leads to a more efficient target detection (i.e., faster RT with similar accuracy) as compared with attending below fixation.[2] Similarly, P3 latency for attended targets was faster when these were presented above fixation (although only significantly so in the 1.3° condition). Our results seem to be in conflict with those in recent studies, in which the perceptual sensitivity of the upper hemiretina (i.e., lower field stimulation) was considered superior to that of the lower hemiretina (Skandries, 1987) and there was usually a RT benefit for stimuli presented in the lower visual field (Previc, 1990). One reason for this difference may lie in the fact that in our experiment the performance effect could reflect both differences in perceptual sensitivity as well as attentional mechanisms. The ERPs showed that the effect of attention started earlier and was larger when the stimuli were presented below fixation; it appeared that upper versus lower field differences were more pronounced for unattended stimuli. Thus, performance in this spatial attention task may be predominantly determined by the efficiency with which the irrelevant stimuli can be ignored. Apparently, irrelevant stimuli cause less distraction when they are presented below fixation, and therefore performance is more efficient in the attend above fixation condition.

Experiment 2

In visual selective attention tasks with stimuli presented in the left and right visual half-fields, the amplitudes of the occipital P1 and N1 components usually are enhanced as the result of spatial attention. This pattern of results was not observed in Experiment 1. To explore whether these divergent findings arose as a result of measuring spatial attention along the vertical meridian or could be attributed to other factors, namely electrode placement and/or the distance between the relevant and irrelevant stimuli, a second experiment was carried out.

The following specific issues were addressed in this experiment. First, it could be that the P1 and N1 effects cannot readily be observed at the midline (Oz) electrode. Recent evidence has shown these components to be larger over lateral brain areas (e.g., Mangun et al., 1993). To control for this possibility, ERPs at two lateral occipital electrodes were measured.

Second, the absence of the P1 and N1 effects in Experiment 1 could be due to the small distance between the relevant and irrelevant stimulus locations. The small distance between stimuli may have resulted in all of them being effectively attended (i.e., all of them fell within the attentional spotlight). Hillyard and Münte (1984) found the typical effects of spatial attention

[1] However, in an independent study that compared 24 (different) younger and 24 older subjects with respect to the same spatial attention tasks, this result was not replicated: For the younger subjects, there was no memory load effect for unattended stimuli.

[2] In the same study mentioned in Note 1, a very similar RT pattern was found. As in the present study, RT was significantly faster (8 ms) in the attend above condition. The ERP patterns of the younger group showed the same effects of attention as in the present study. The selective attention effect for the older subjects was attenuated but in principle showed the same pattern.

when the stimuli were presented at locations that were easy to discriminate (at the horizontal meridian, 5° to the right or left of fixation). These effects disappeared when the stimuli were hard to discriminate (3° above fixation, 0.3° to the right or left of the vertical meridian). In addition, the effect of attention on the P1 and N1 amplitudes shows a gradient structure across the visual field (Mangun & Hillyard, 1987, 1988, 1990). That is, P1 and N1 amplitudes are largest when attention is directed at the location of stimulus presentation and systematically decrease the farther the attentional focus is removed. Thus, P1 and N1 amplitudes may still be enhanced even when attention is directed at a location several degrees away from the stimulus. These findings have been interpreted as demonstrating that attentional resources are not narrowly constricted to a small visual area but instead are more broadly distributed, with fewer resources allocated to areas farther away from the attended location. Similarly, Wijers et al. (1989a) observed that the effect of attention on P1 and N1 amplitudes generalized to locations close to the attended location; these authors, however, found no evidence for a gradient structure. If, in Experiment 1, the irrelevant location still received attentional resources, this could account for the absence of the P1/N1 effects.

Experiment 2 used a task similar to that of Experiment 1 but increased the separation between the relevant and irrelevant locations (3° above and below fixation). This condition was compared with two conditions in which the relevant and irrelevant locations were at the horizontal meridian, to the right and left of fixation. To investigate the effect of discriminability, we compared a condition with a small separation, comparable to that of Experiment 1 (1.3° to the right and left) with a condition with a larger separation (3° to the right and left).

Method

The experimental procedures employed in Experiment 2 were in many respects identical to those of Experiment 1. Differences are discussed below.

Subjects

Twelve subjects (six women, six men) served as paid volunteers. Their ages were between 20 and 25 years. None of the subjects had participated in Experiment 1.

Stimuli

The subjects performed selective search tasks with a memory load of one letter. There were three different conditions. In one of the conditions, the relevant and irrelevant letters were presented above and below fixation, as in Experiment 1. In the present experiment, the separation between the stimulus positions and fixation was larger than in Experiment 1, namely 3°, and was termed the vertical-easy condition. In addition, there were two conditions in which the relevant and irrelevant locations were positioned to the right and left of fixation, at the horizontal meridian. In the horizontal-easy condition, the separation was 3°; in the horizontal-hard condition, it was 1.3°.

Procedure

The subjects received six series of 240 stimuli. For each of the different stimulus presentation conditions vertical-easy, horizontal-easy, and horizontal-hard, they received one series in which they attended to one of the stimulus positions and another series in which they attended to the other stimulus position (i.e., attend-above vs. attend-below and attend-left vs. attend-right conditions). The order of administration of the three stimulus presentation conditions was counterbalanced across subjects. The two blocks within each of these three conditions were presented in succession, and the order of the two blocks was also counterbalanced across subjects. At the beginning of each of the three stimulus presentation conditions, subjects received one block of 240 stimuli as practice.

Recording

The EEG was recorded from Fz, Cz, Pz, Oz, inion, Ol, and Or. Ol and Or were positioned at 50% of the distance between Oz and T3 and T4, respectively.

Data Analysis

Average ERPs were computed separately for each electrode location for all stimulus classes, which were defined by stimulus location (above vs. below fixation or left vs. right of fixation); attention (attention was directed at the location of stimulus presentation vs. directed at the opposite location); letter category (memory set letter vs. nontarget letter); memory load condition (M1 and M4); and, if applicable, small versus larger stimulus–fixation distance.

For the midline electrodes, each ERP was divided into 33 periods of 30 ms, from 10 to 1,000 ms poststimulus, and the mean amplitudes of the ERPs in these intervals were submitted as dependent variables to SPSSPC+ MANOVAs. In contrast to Experiment 1, an univariate approach was used because only 12 subjects were tested in the present experiment. Small sample sizes lead to a drop in statistical power if the multivariate approach is used (but see O'Brien & Kaiser, 1985, for a discussion of this matter). For the lateral electrodes (Ol, Or), P1 amplitudes and latencies were determined as the most positive signal value in the 100–200-ms range and N1 amplitude and latency as the most negative signal value in the 170–270-ms range. P3b latency and amplitude was evaluated using an interactive peak detection program, which used a search window in the 440–760-ms range.

ERP and behavioral data were analyzed as follows. We first compared the tasks using horizontal and vertical meridian as selection cue (both 3° condition; horizontal-easy vs. vertical-easy). Then analyses were carried out comparing the horizontal-easy with horizontal-hard condition. The third set of analyses was carried out on each condition separately to estimate the effects of attention within each condition. The interval analyses were all carried out for each electrode separately. P1 and N1 amplitude were tested with an additional variable, hemisphere (i.e., Ol vs. Or).

Results

Performance Data

The analyses of the reaction times showed that within the vertical-easy condition RT was 29 ms faster in the attend-above condition than in the attend-below condition ($F[1,11] = 8.52$, $p < .05$). The comparison of the horizontal-easy condition with the horizontal-hard condition showed that RT was 16 ms faster in the easy condition ($F[1,11] = 5.74$, $p < .05$). There was no significant difference between the horizontal-easy and the vertical-easy conditions ($F[1,11] = 2.38$, $p > .1$) (Table 4).

None of the analyses for the error data reached significance.

Table 4. *Behavioral Data for Target Stimuli of Experiment 2 for Large and Small Stimulus-Fixation Distances and Position of Attended Stimuli*

Distance/position	RT (ms)	% correct	No. misses
Large			
Up	407	99	0.8
Down	435	98.5	1.3
Right	411	98	1.7
Left	414	99	0.7
Small			
Right	432	96.5	2.7
Left	425	98.5	1.2

ERPs

P3b. The relevant targets evoked a parietally maximal P3b component (Table 5). The only significant effect for P3b latency was the comparison between the horizontal-easy and horizontal-hard conditions. P3b latency was 21 ms earlier in the easy condition ($F[1,11] = 5.82, p < .05$). Although similar to Experiment 1, the faster P3b latency in the attend-above condition as compared with attend-below (13 ms) did not reach significance.

Effects of stimulus presentation position. The effect of presenting a stimulus above or below fixation replicated the results of Experiment 1. Again, in an early latency range, the ERPs at posterior electrodes showed a positive shift for stimuli presented above fixation as compared with stimuli presented below fixation. This effect was most pronounced at Oz, where the responses to stimuli above fixation only showed an early positivity and the responses to stimuli below fixation only showed a negativity. The analyses of the interval data revealed that the effect of presentation position was significant in the 160–210-ms range at Fz, 130–210 ms at Cz, and 100–210 ms at Pz, Oz, and the inion. At both lateral occipital electrodes, P1 and N1 components could be seen for both presentation positions. The P1 was much more pronounced for stimuli above fixation (3.4 μV above vs. 1.6 μV below), whereas the N1 was much more pronounced for stimuli below fixation (−2.8 μV above vs. −5.8 μV below). These effects were significant for both P1 and N1 amplitude (P1: $F[1,11] = 15.9, p < .01$; N1: $F[1,11] = 15.5, p < .01$).

Table 5. *P3b Latency and Amplitude Elicited by Target Stimuli in Experiment 2 for Large and Small Stimulus-Fixation Distances and Position of Attended Stimuli*

Distance/position	Latency (ms)	Amplitude (μV)
Large		
Up	440	19.3
Down	453	17.5
Right	444	18.6
Left	446	19.4
Small		
Right	470	18.7
Left	462	18.8

The P1 and N1 components showed clear lateralizations over the left and right hemispheres (Ol vs. Or) as a function of stimulus presentation to the right and left visual half-fields. The P1 component was larger at the electrode ipsilateral to the visual field of stimulus presentation (3.2 μV ipsilateral vs. 2.3 μV contralateral), whereas the N1 was larger contralaterally (−1.4 μV ipsilateral vs. −5.2 μV contralateral). The latencies of these ERP components were delayed at the ipsilateral electrodes as compared with the contralateral electrodes (P1 latency: 158 ms ipsilateral vs. 130 ms contralateral; N1 latency: 212 ms ipsilateral vs. 196 ms contralateral). These effects were indicated by significant Hemisphere × Visual Field interactions for P1 latency ($F[1,11] = 63.7, p < .001$), N1 latency ($F[1,11] = 5.7, p < .05$), and N1 amplitude ($F[1,11] = 19.3, p < .01$). This pattern of results has been reported previously (e.g., Rugg, Lines, & Milner, 1985; Rugg, Milner, Lines, & Phalp, 1987; Wijers et al., 1989a). These lateralization effects were not significantly influenced by the stimulus–fixation separation: the horizontal-hard condition showed effects similar to those of the horizontal-easy condition (Figure 5).

Effects of selective attention. Effects of attention were analyzed for nontarget stimuli only. In the vertical condition, the effects of attention at the midline electrodes (Fz, Cz, Pz, Oz) were very similar to the effects found in Experiment 1 (Figure 6a). Again, an early positivity, most prominent at Fz (onset at about 140 ms), was followed by a centrofrontal negativity (between about 240 and 320 ms), after which a late parietocentral positivity developed. At the lateral electrodes (Ol and Or), the effect of attention became visible as bilateral enhancements of the P1 and N1 components. In the subtraction potentials, these early posterior effects became visible as a positive-negative difference wave. The onset of this difference was somewhat earlier than that at the anterior electrodes (about 120 ms). In Experiment 1, we found that the ERPs for unattended stimuli presented below fixation showed increased late negativity (between about 300 and 500 ms) as compared with those for unattended stimuli above fixation. In the present experiment, the ERPs for both the attended and unattended stimuli below fixation showed such increased negativity, resulting in a difference wave that was more independent of the presentation position of the stimulus. However, such a difference is still visible on the occipital electrodes (Oz, Ol, Or).

Analysis of the mean amplitude data in the vertical-easy condition showed effects of attention at the midline electrodes in the ranges 190–240 ms, 280–330 ms, 430–480 ms, and 550–660 ms at Fz, 250–330 ms, 400–510 ms, and 580–660 ms at Cz, 160–180 ms, 250–300 ms, and 370–540 ms at Pz, 160–180 ms and 370–450 ms at Oz, and 190–210 ms at the inion. The peak amplitudes of both the P1 and N1 were significantly changed by attention (P1: $F[1,11] = 20.7, p < .01$; N1: $F[1,11] = 10.3, p < .01$). These effects were independent of the stimulus position (see Figure 5).

The horizontal conditions showed a very similar pattern of results (Figures 6b and c). In the horizontal-easy versus vertical-easy comparison, the tests on the mean amplitude values showed no systematic Attention × Condition interactions. The tests on the peak measures showed significant effects of attention on P1 and N1 amplitudes (P1: $F[1,11] = 29.2, p < .001$; N1: $F[1,11] = 16.3, p < .01$) but no interaction of Attention × Condition (horizontal vs. vertical presentation).

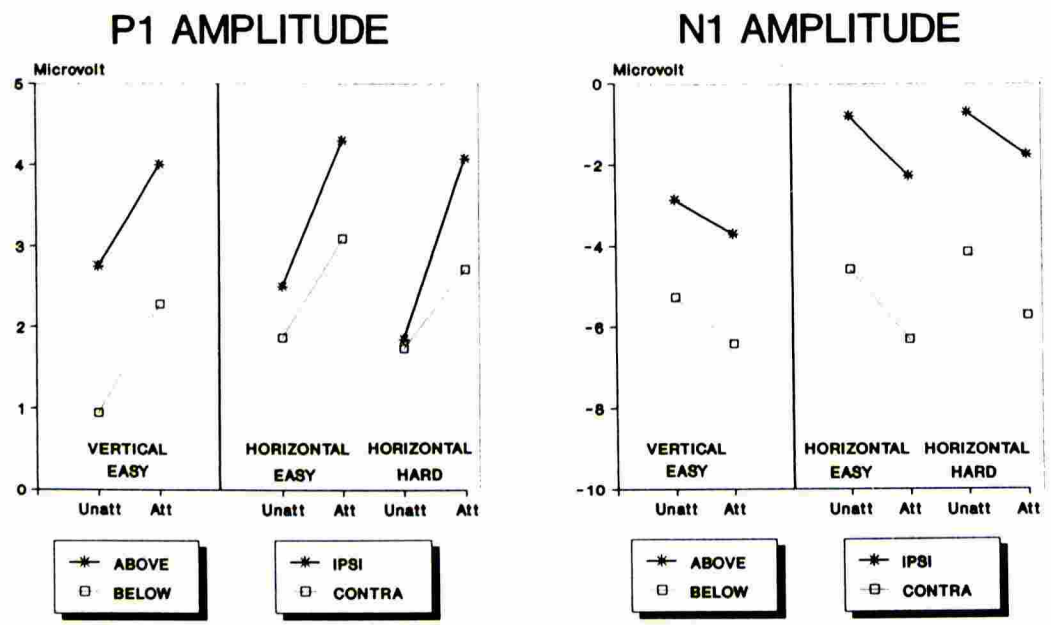
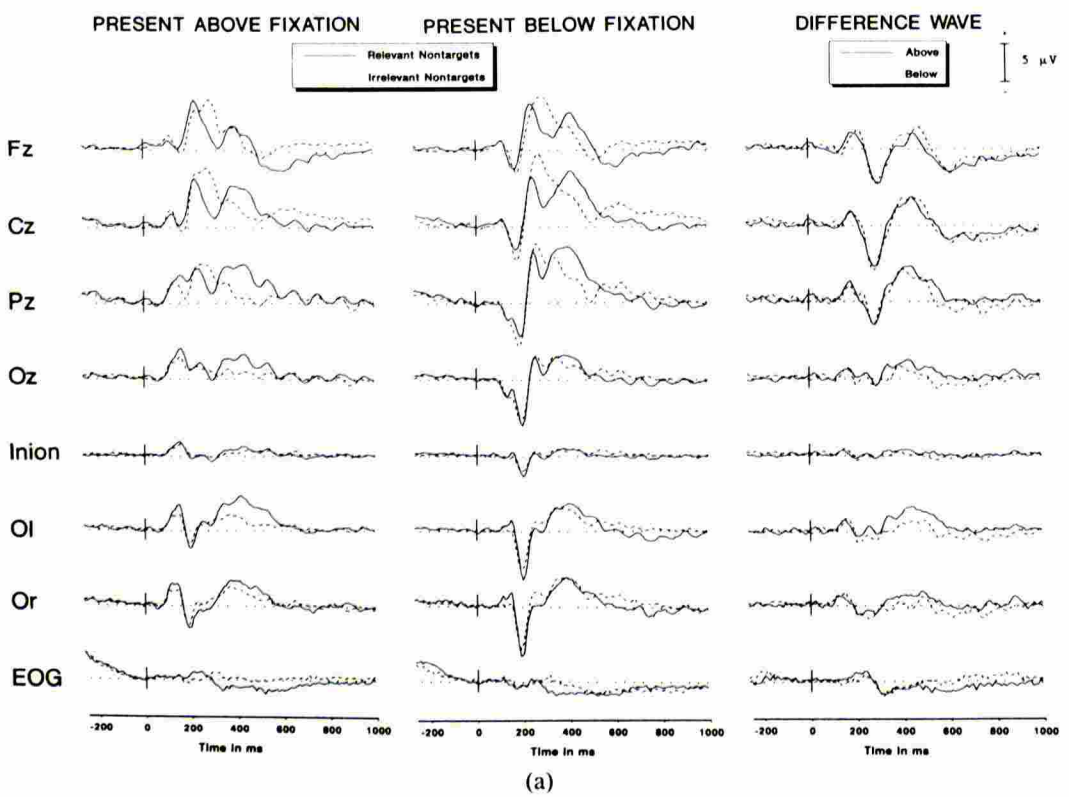


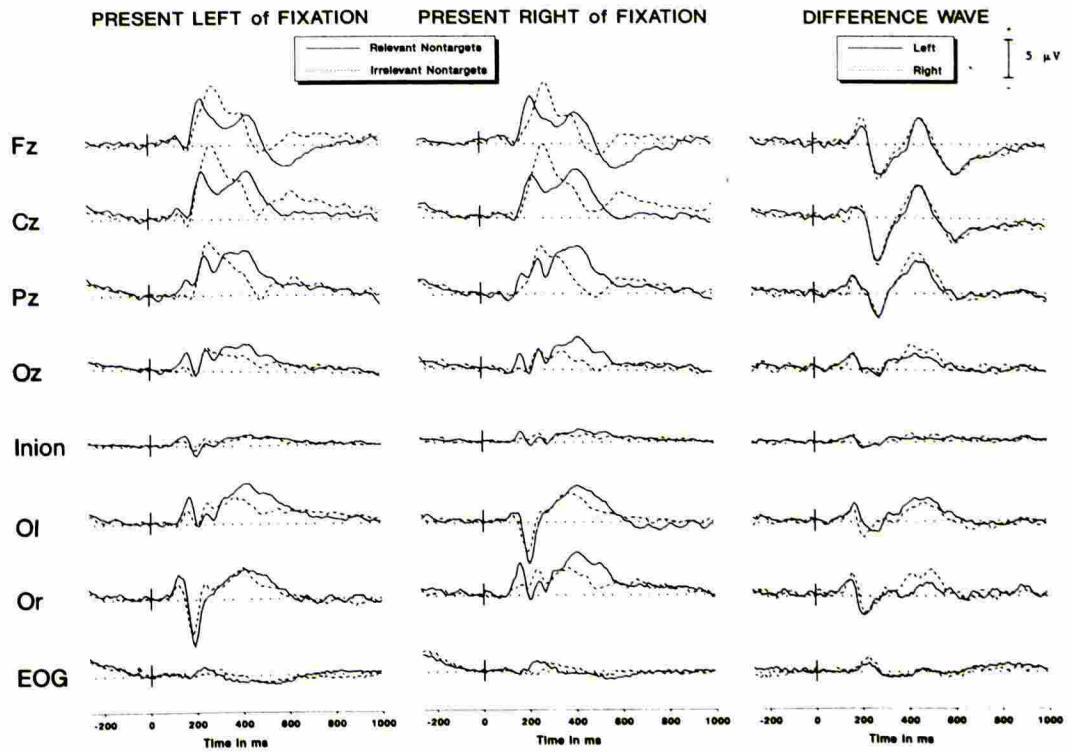
Figure 5. P1 and N1 amplitude for attended and unattended nontargets in the vertical-easy, horizontal-easy, and horizontal-hard conditions.

The only difference between the horizontal-easy condition and the vertical-easy condition was that in the horizontal condition the attention effects showed (small) differences in hemispheric lateralizations as a function of visual field of stimulus presentation. The P1 enhancement was somewhat larger at the occipital electrode ipsilateral to the visual field of stimulus presentation, whereas the N1 enhancement tended to be slightly larger contralaterally. Only the lateralization of the P1 atten-

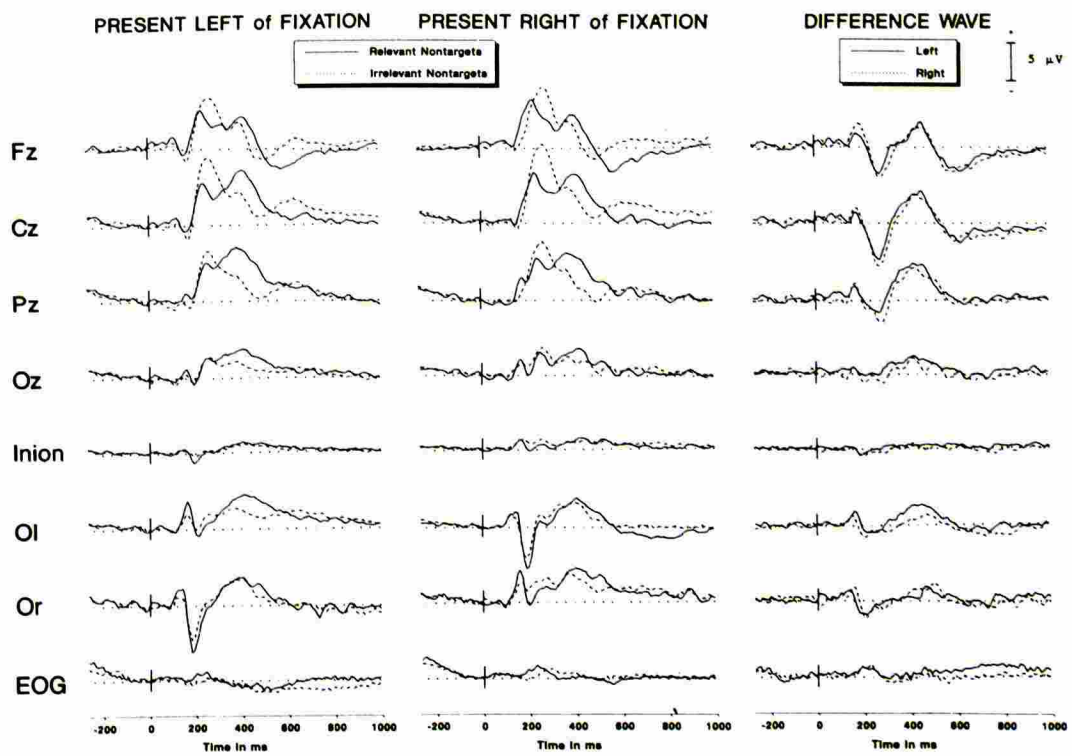


(a)

Figure 6. The left and middle panels show ERPs for relevant nontarget (solid line) and irrelevant nontarget (dashed line) stimuli for presentation above (left panel) and below (middle panel) fixation. The right panel shows difference waves for attended minus unattended nontarget stimuli for present above (solid line) and present below (dashed line) fixation. (a) Vertical-easy condition. (b) Horizontal-hard condition. (c) Horizontal-easy condition. (*Figure continues*)



(b)



(c)

Figure 6 continued.

tion effect was statistically significant, as evidenced by a Visual Field × Attention × Hemisphere interaction ($F[1,11] = 12.2$, $p < .01$). Comparable results were reported by Rugg et al. (1987) and Wijers et al. (1989a).

For the easy and hard horizontal conditions, there were no differences in the effects of attention between these conditions (see also Figure 5). The tests over both horizontal conditions showed significant effects of attention on P1 amplitude

($F[1,11] = 22.9$, $p < .01$) and N1 amplitude ($F[1,11] = 21.6$, $p < .01$) but no interaction of attention with condition (hard vs. easy).

General Discussion

Experiment 2 replicated some of the major findings of Experiment 1. Stimulus presentation position (above vs. below fixation) influenced ERP morphology in the same way as in Experiment 1. Performance was again more efficient when a position above fixation was attended than when attention was directed below fixation. The reaction time benefit in Experiment 2 (29 ms) was larger than in Experiment 1 (11 ms), suggesting that this effect increases with larger spatial separations between the upper and lower field stimulus positions. However, in Experiment 1 the ERP effects of spatial attention also depended on stimulus position; this effect was not clearly visible in Experiment 2, which may suggest that attentional factors play a more important role in the superiority of the upper visual field for central vision than for more peripheral vision.

The ERPs of Experiment 2 that were measured at the midline electrodes showed spatial attention effects that closely resemble those obtained in Experiment 1. The lateral occipital electrodes, which were only measured in Experiment 2, showed the usual spatial attention effect, consisting of the enhancement of the posterior P1 and N1 components. The size of this effect was very similar for all three conditions; it did not depend on whether stimuli were being discriminated along the horizontal or vertical meridian and was independent of the spatial separation between stimuli along the horizontal meridian. The P1/N1 spatial attention effect was much more pronounced at lateral occipital electrodes as compared with Oz (however, that the horizontal hard condition showed a clearly visible P1/N1 enhancement at Oz); this probably explains the absence of the effect in Experiment 1 where only Oz was measured. Therefore, we conclude that similar mechanisms are involved in horizontal and vertical spatial attention. A similar conclusion was reached by Mangun et al. (1993). These authors presented stimuli in four visual quadrants. As usual, P1 and N1 amplitudes were enhanced when stimuli were presented at the attended location as compared with when attention was directed at the opposite visual half-field. Furthermore, the same effect was obtained when attention was directed to the opposite quadrant in the same visual half-field.

At the anterior electrodes, the most distinctive feature besides the later N2b-P3a complex, which has consistently been obtained in other investigations as well (Okita et al., 1985; Wijers et al., 1989c), was an early positivity. Such an effect has not been reported previously. More commonly, early anterior negativities are reported. Rugg et al. (1987), for instance, report an anterior negativity with the same onset latency as the occipital effects. In the present research, the anterior effects seem to lag slightly behind the posterior effects, suggesting that they originate from different cortical sources. Yet, anterior positivity was reported when selective attention was directed to the color of stimuli (e.g., Hillyard & Münte, 1984; Wijers et al., 1989b, 1989c). However, in these instances the effect consisted of an enlargement of the frontal P2 peak, whereas in the present research the effect seems to consist of an endogenous positivity resulting in an apparently later P2 peak latency for unattended stimuli.

The conditions with a smaller (1.3°) and a larger (3°) distance between the attended and unattended stimulus positions at the horizontal meridian showed no difference with respect to the ERP effects of attention, even though the reaction times were faster in the easy condition. Because we did not measure the lateral occipital electrodes for vertical conditions with stimulus–fixation distances smaller than 3°, we cannot be absolutely sure that there is no effect of distance on the P1 and N1 effects with attention along the vertical meridian. Nevertheless, because the vertical-easy and horizontal-easy conditions were virtually identical and because there were only minor effects of distance for the other electrodes in Experiment 1, we conclude that for all distance conditions qualitatively similar effects have been obtained. Therefore, spatial selectivity apparently only breaks down for relevant–irrelevant stimulus position distances less than 1° (e.g., the 0.3° distance employed by Hillyard & Münte, 1984). In addition, the present results demonstrate that attentional resources were narrowly constricted to the attended location in the horizontal-hard condition. If attentional resources had been unevenly distributed over a visual area of several degrees of visual angle (i.e., if there were a gradient of attention: Mangun & Hillyard, 1987, 1988, 1990), then the concentration of resources at the irrelevant location should have been much higher in the horizontal-hard condition than in the horizontal-easy condition, and accordingly the effect of attention should be smaller in the hard condition. This result was clearly not what was observed, which could mean that the area of visual space over which attention is distributed is variable (i.e., a variable spotlight or zoom lens, e.g., Eriksen & St. James, 1986) and is smaller when to-be-attended and to-be-ignored positions are closer together. Alternatively, there may be a gradient of attention within a visual half-field but attentional resources may not spread across the meridians.

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